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(54) Abstract Title

Optical switch positioned between multi-wavelength light sources and a plurality of modulators

(57) An Optical Communications System comprising one or more light sources each for producing light in a different part of the spectrum; a plurality of optical modulators each for modulating with an input signal the light produced by the one or more light sources; an optical switch connected between the one or more light sources and the plurality of optical modulators for switching the light output from the or each of the light sources to a different selected one of the plurality of optical modulators. Advantageously, the optical switch is also connected to the plurality of optical modulators for switching the modulated light output from the selected one or ones of the plurality of optical modulators. Preferably, the modulated light outputs are routed back through the switch in the opposite direction.

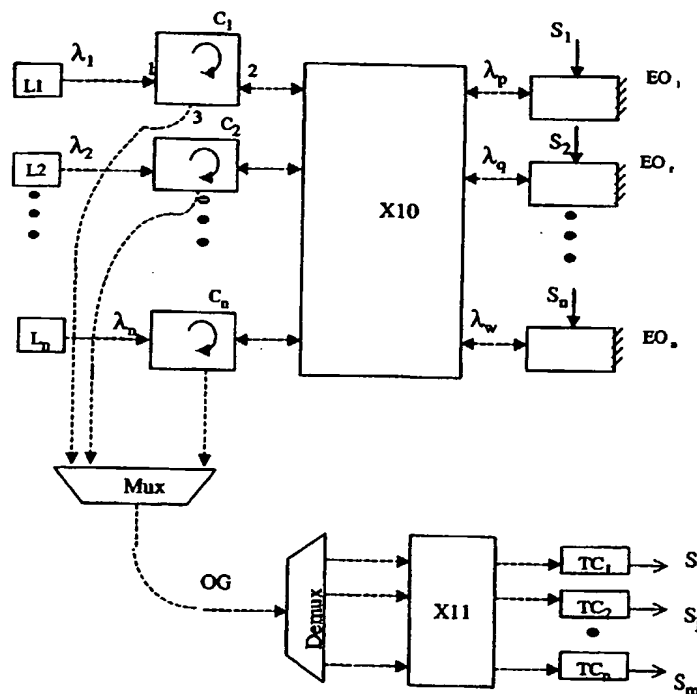


Fig 7.

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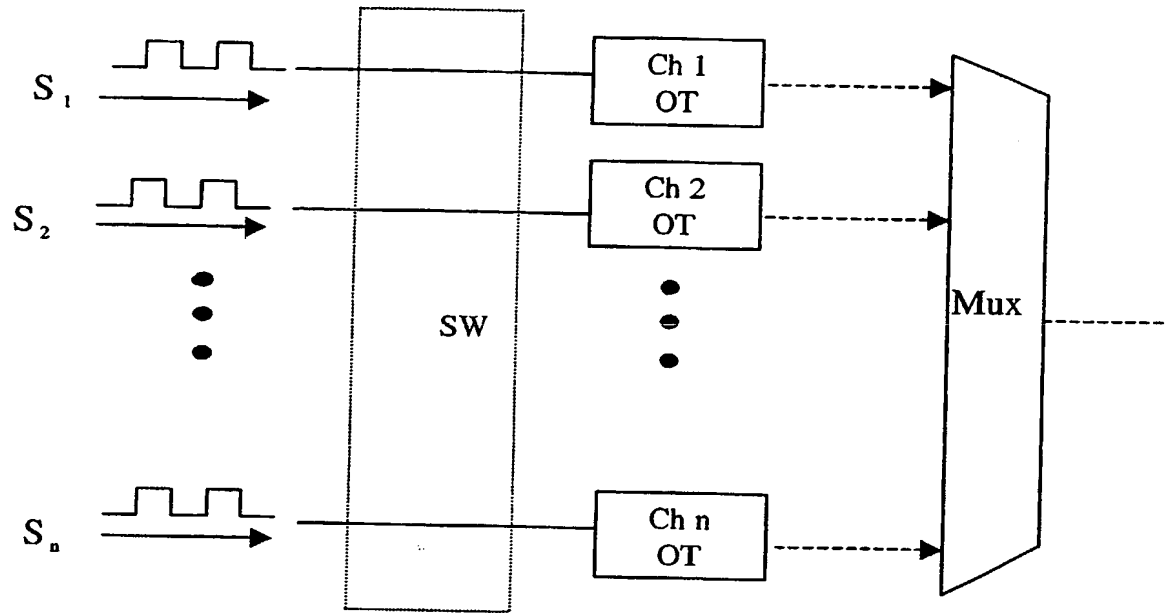


Fig. 1

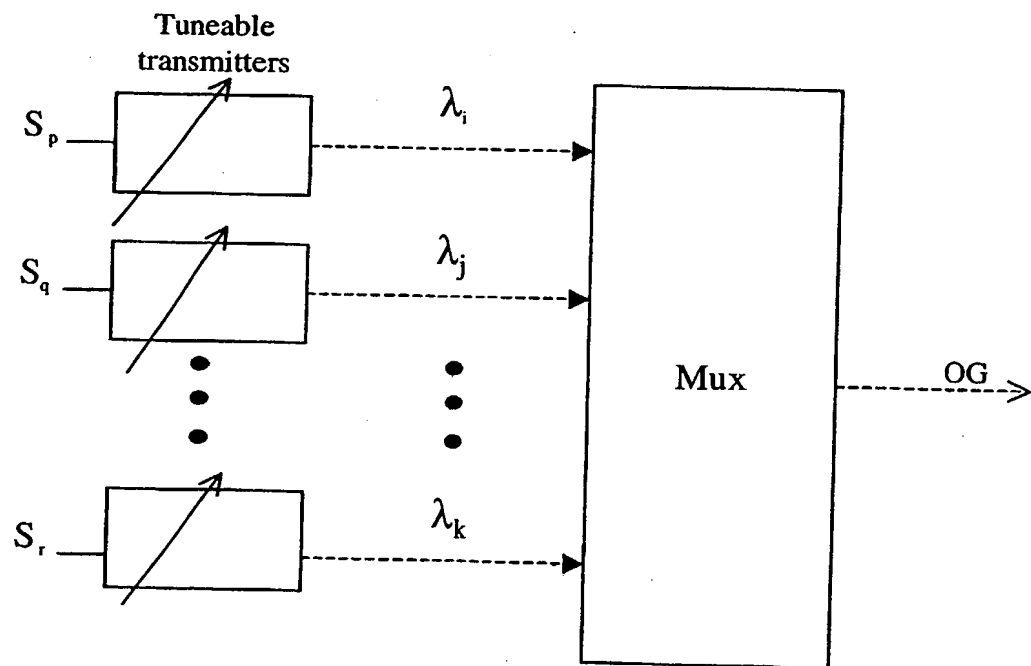


Fig 2

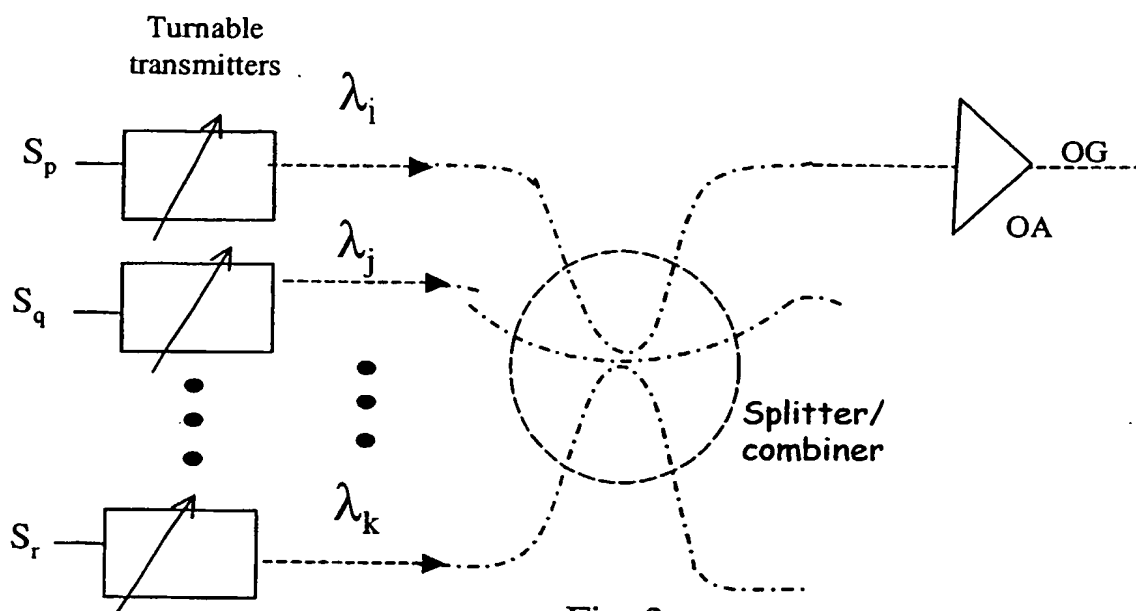


Fig. 3.

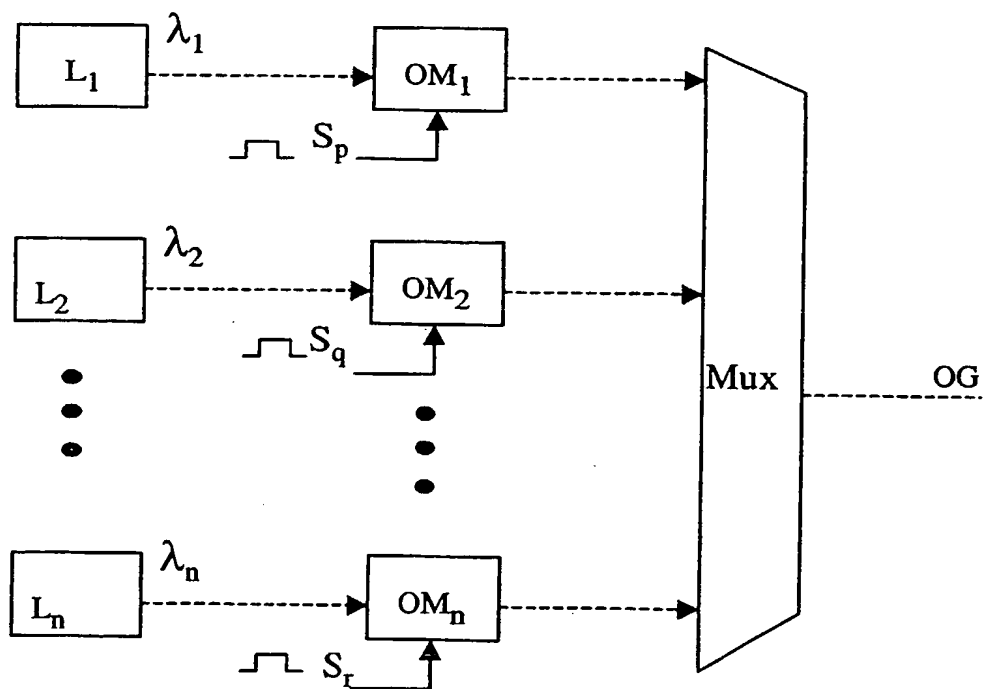


Fig 4

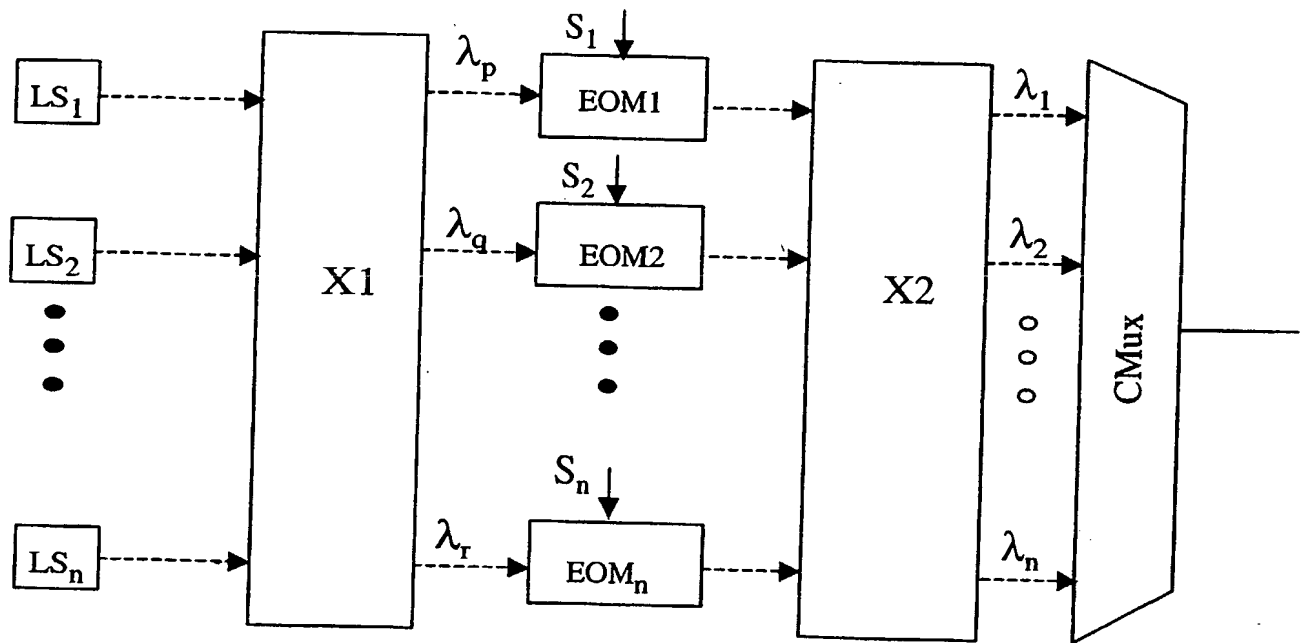


Fig 5

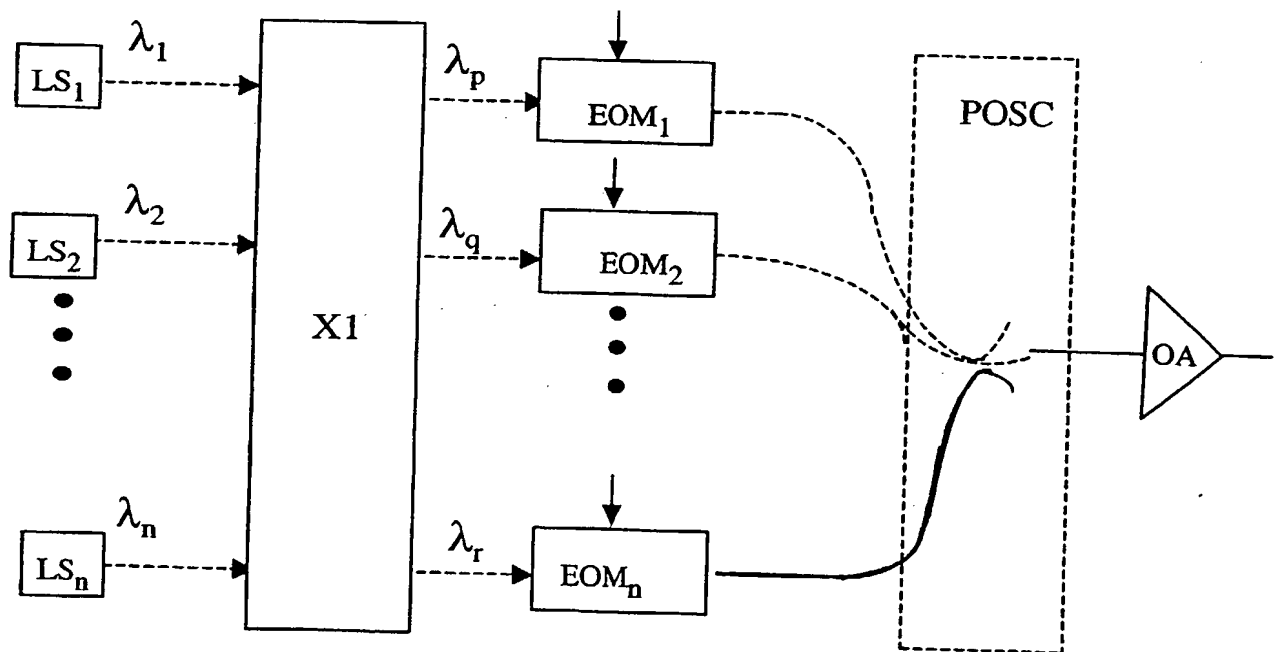


Fig 6.

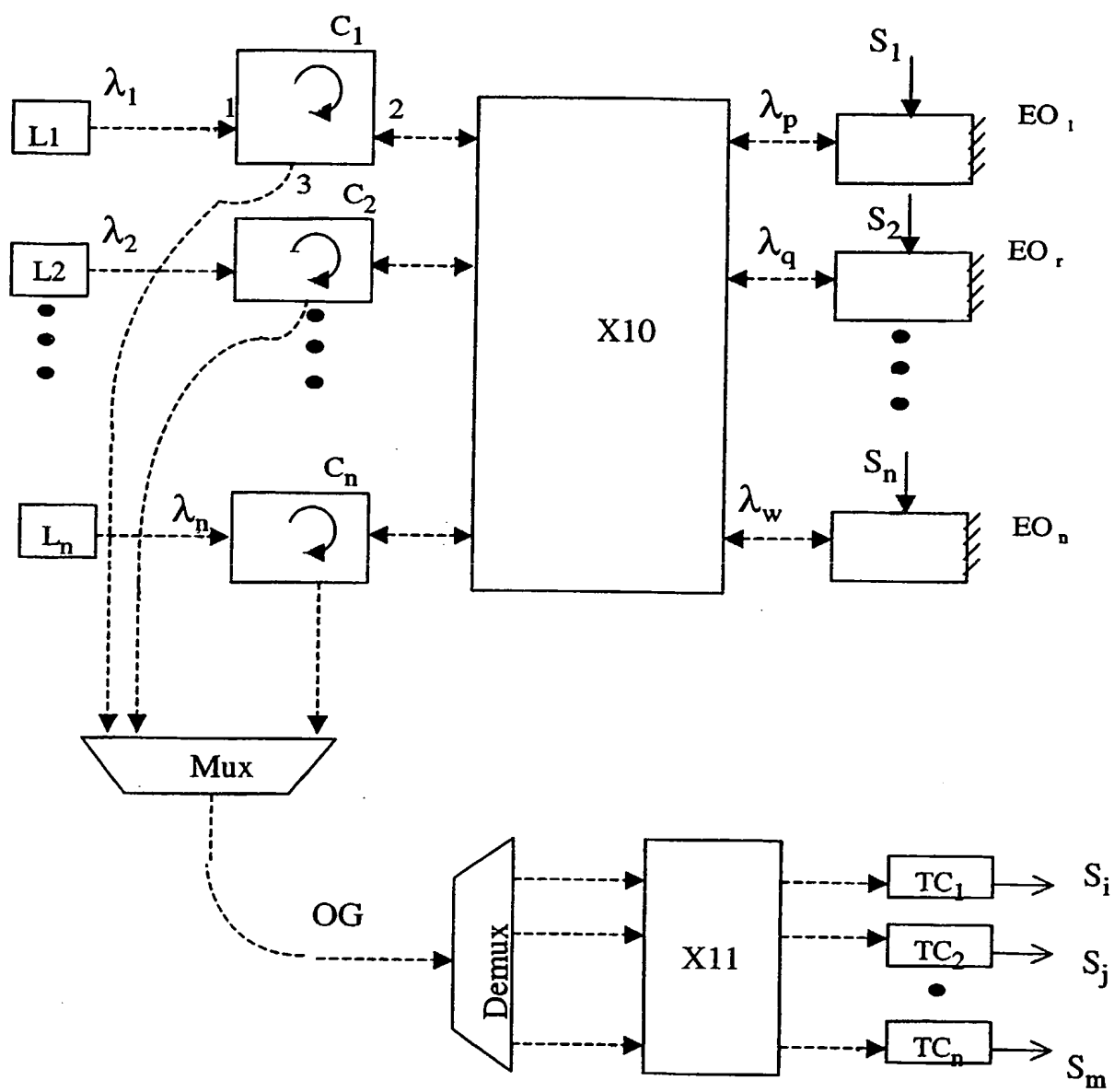


Fig 7.

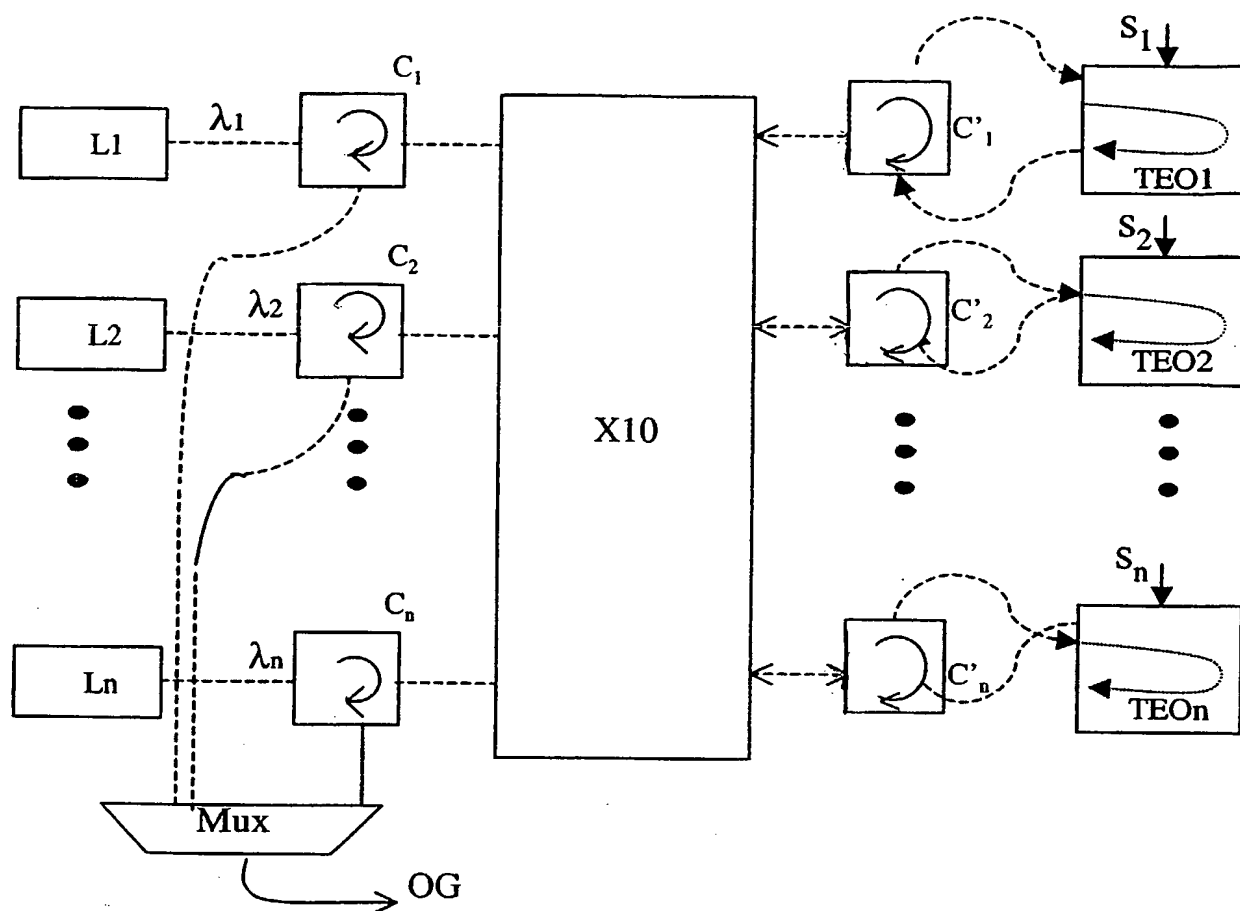


Fig 8

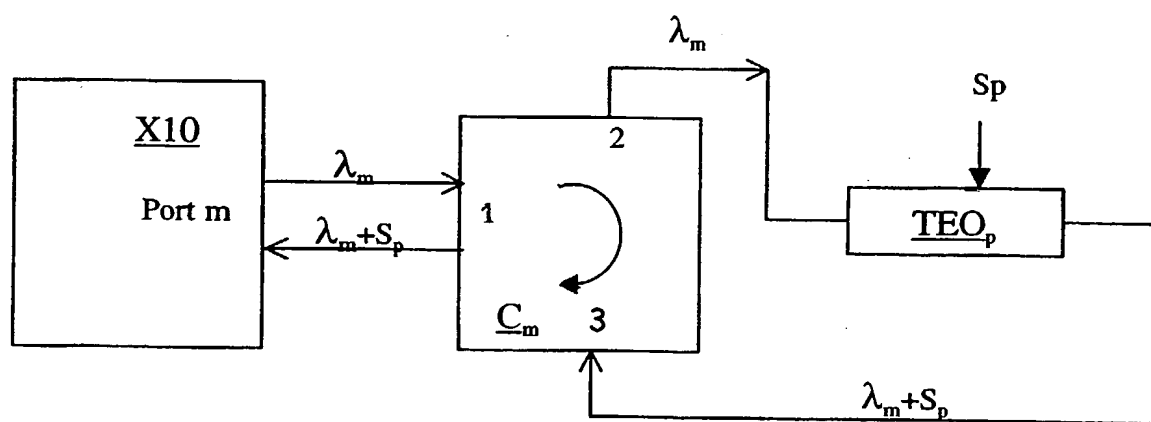


Fig 9.

Optical Communications System

The present invention relates to the field of optical communications systems.

5 Wavelength division multiplex (WDM) line and ring systems are becoming preferred solutions for carrying high communications traffic volumes. Signals are carried as modulation on optical carriers, each carrier occupying a distinct part of the spectrum. These systems require the generation of an optical carrier at a selected wavelength at each location where this wavelength is required to be transmitted. The cost of the
10 transmitter cards where such generation is performed is a major contribution to the total cost of the network.

There is a need for flexibility so that any input signal can be carried on any wavelength, and the wavelength of the carrier can be changed without the need for
15 moving any physical boards or plugs. Hence there is a need for a switch arrangement for the optical signals to allow each input signal to be allocated to a selected carrier. It is preferable to carry the signals as modulated carriers on shared optical guides (i.e. including optical fibre and optical waveguides). Hence, in combination with the switch arrangement, there is a need in some applications for optically multiplexing a
20 plurality of the signals onto a single transmission fibre.

Fixed wavelength transmitters are known and multiplexing onto the transmission fibre may be achieved conventionally by using a passive arrangement of diffraction gratings, interference filters or optical integrated waveguides (e.g. M.K.Smit: "New
25 focusing and dispersive planar component based on an optical phased array",

Electronics Letters, vol. 24, no. 7, pp.385-386, Mar, 1988; and A.R. Vellekoop and M.K. Smit: "Four-Channel integrated-optic wavelength demultiplexer with weak polarisation dependence", Journal of Lightwave Technology, vol.9, no 3, pp.310-314, MAR.1991, and C Dragone: "An $N \times N$ optical multiplexer using a planar arrangement of two star couplers", Photonics Technology Letter, vol.3, no 9, pp.812-815, Sept. 1991). Flexibility of connection may be accomplished by changing the electrical routing into the optical transmitters by means of a patch panel or an electrical space switch. However, this electrical switching becomes problematic for high time division multiplex (TDM) rates such as 10Gbits/s and above and where switch reconfigurability is called for in remote locations.

An alternative arrangement is to use tuneable wavelength transmitters with outputs modulated by input electrical signals and to achieve the flexibility by means of the actively routed optical multiplexer (or active WDM combiner) as described in British patent application GB 9826108.4 assigned to Marconi Communications and incorporated herein by reference (see in particular Figures 3 to 6 and the corresponding parts of the description). Currently such active WDM combiners are not commercially available and the only practical way to achieve such flexibility today is to use a passive splitter/combiner, eg a fixed fibre combiner or waveguide combiner. However, such splitter/combiners are limited so that they will only couple (for a perfect coupler) $1/n$ th of the input power, where n is the number of paths combined or split. With 32 to 100 channels of WDM now commonplace the losses experienced with such an arrangement are significant – typically requiring compensation by use of optical amplifiers.

For high speed optical communications, better optical signal quality can be achieved with an unmodulated (i.e. not tunable) laser that has a pure spectrum operated in combination with a separate optical modulator with outputs modulated by input electrical signals, e.g. a DFB diode laser and an Electro-Absorption Modulator or

5 Mach-Zehnder Lithium Niobate Modulator.

There is a need to be able to take any input signal and transmit it on any carrier wavelength.

10 The present invention provides an Optical Communications System comprising one or more light sources each for producing light in a different part of the spectrum; a plurality of optical modulators each for modulating with an input signal the light produced by the one or more light sources; an optical switch connected between the one or more light sources and the plurality of optical modulators for switching the

15 light output from the or each of the light sources to a different selected one of the plurality of optical modulators.

Embodiments of the present invention will now be described by way of example with reference to the drawings in which :

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Figures 1 to 4 show optical communications systems of the prior art;

Figures 5 to 8 show optical communications system according to embodiments of the present invention;

Figure 9 shows an aspect of the optical communications system of Figure 8 in more

25 detail.

Figure 1 shows fixed wavelength optical transmitters OT in combination with a conventional optical multiplexer Mux for multiplexing the signals onto a transmission fibre OG. Flexibility is achieved by an electrical switch or patch panel
 5 SW allowing the routing of the electrical signals S_1, S_2, \dots, S_n into the optical transmitters to be varied.

Figure 2 shows an alternative arrangement using tuneable wavelength transmitters with outputs modulated by input electrical signals S_p, S_q, \dots, S_r with the flexibility of a
 10 actively routed optical multiplexer (or active WDM combiner Mux). Figure 3 shows the use of a passive splitter/combiner, eg a fixed fibre combiner or waveguide combiner in place of the actively routed optical multiplexer of Figure 2 in combination with an optical amplifier OA..

15 Figure 4 shows unmodulated lasers L_1, L_2, \dots, L_n that each produce a spectrally pure output $\lambda_1, \lambda_2, \dots, \lambda_n$ to a fixed one of an array of optical modulators OM_1, OM_2, \dots, OM_n whose outputs are modulated by input electrical signals S_p, S_q, \dots, S_r . The outputs of the optical modulators are taken to optical multiplexer Mux.

20 Two switch Solution

As shown by way of example in Figure 5, the invention provides a way to avoid electrical switching of the input signals. An array of light sources LS_1, LS_2, \dots, LS_n each providing a different carrier wavelength $\lambda_1, \lambda_2, \dots, \lambda_n$ are each connected to a different
 25 input of a first optical $n \times n$ switch X1 (i.e. having n input and n output ports). Each

output of the switch X1 is connected to a different one of an array of electro-optical modulators $EOM_1, EOM_2 \dots EOM_n$ (such as electro absorption, Mach-Zehnder interferometric waveguide type or electromechanical). Each electro-optical modulator EOM receives an electrical input carrying a signal, i.e. $S_1, S_2 \dots S_n$ and imposes the

5 signal onto the optical carrier (i.e. one of $\lambda_p, \lambda_q \dots \lambda_r$) received from first optical switch X1. Hence the traffic carried in each input signal can be routed onto a desired wavelength carrier by operation of first optical switch X1, i.e. by switching of optical, not electrical, signals. The modulated optical output from each electro-optic modulator EOM is connected to a different one of a plurality of inputs of the second

10 nxn optical switch X2. Each output of the second optical switch X2 is connected to a different input of optical multiplexer Cmux. Optical multiplexer Cmux has frequency sensitive inputs requiring the correct frequency to be applied to each input for correction operation. Second optical switch X2 allows the optical signals output from electro-optical modulators EOM to be routed so that each input to optical multiplexer

15 Cmux receives the correct frequency carrier. The single output of optical multiplexer Cmux is connected to a single optical guide OG. Optical multiplexer Cmux provides that each of the wavelengths can be combined into a single fibre. As an alternative to optical multiplexer Cmux, an optical combiner (not shown) may be used.

20 Alternatively, as in Figure 6, the second switch can be replaced by a passive optical splitter/combiner POSC which combines all optical signals at its inputs. The passive optical splitter/combiner does not have frequency sensitive inputs, hence second optical switch X2 is not needed. As indicated above, the loss introduced by optical splitter/combiner POSC may be overcome by using optical amplifier OA, connected

25 at the POSC output.

Single Switch Solution

A further preferred embodiment, in which the optical switch and optical modulator are used in a reflective manner, is shown in Figure 7. As shown in Figure 7, light is generated in plurality of lasers $L_1, L_2 \dots L_n$. The output ($\lambda_1, \lambda_2 \dots \lambda_n$) from each laser is coupled into a different one of plurality of optical circulators $C_1, C_2 \dots C_n$. An optical circulator transmits light from one port to the next port in sequence but has very high attenuation (e.g. >40dB) in the reverse port sequence. Hence, in Figure 7, light entering the first port 1 of optical circulators $C_1, C_2 \dots C_n$ is coupled to the second port 2 of that circulator with low loss, light entering the second port is coupled to the third port 3 with low loss and light entering the third port is coupled with the first port with low loss. Each one of optical circulators $C_1, C_2 \dots C_n$ transmits the light received from the respective laser to a different input of nxn optical switch X10.

Each output of optical switch X10 is connected to a different one of a plurality of reflective optical modulators $EO_1, EO_2 \dots EO_n$ (i.e. modulators that reflect the modulated carrier). Optical switch X10 allows light received at any wavelength to be routed to any one of the optical reflector modulators $EO_1, EO_2 \dots EO_n$. Each one of optical reflector modulators $EO_1, EO_2 \dots EO_n$ receives an electrical input $S_1, S_2 \dots S_n$ carrying a signal and imposes the signal onto the optical carrier received from optical switch X10. Hence the traffic carried in each signal can be transferred onto a desired wavelength carrier by operation of optical switch X10.

As modulators $EO_1, EO_2 \dots EO_n$ are reflective, the modulated carrier is output at the same port as that used to receive the unmodulated carrier from optical switch X10 and is coupled back into optical switch X10 at the same port as that used to output the unmodulated carrier. Optical switch X10 is bi-directional and the modulated carrier
 5 follows the same route through the switch as the corresponding unmodulated carrier, but in the opposite direction and is thus routed back in the direction of the source ($L_1, L_2 \dots L_n$) that generated the carrier on that wavelength.

On exiting optical switch X10, the modulated carrier enters the optical circulator of
 10 plurality $C_1, C_2 \dots C_n$ that passed the corresponding unmodulated carrier at the second port 2 thereof. The optical circulator routes the modulated carrier to a third port 3 thereof connected to an input to optical multiplexer Mux. As before, the optical multiplexer has frequency sensitive inputs requiring the correct frequency to be applied to each input. The reflective arrangement described above, ensures that the
 15 modulated carriers are routed so that each input to optical multiplexer Mux receives the correct frequency carrier. The single output of optical multiplexer Mux is connected to a single optical guide OG for transmitting the combined optical carriers therethrough. Optical multiplexer Mux provides that each of the wavelengths can be combined into a single transmission fibre.

20

At the receive end of the optical guide OG the different carrier frequencies are split in optical demultiplexer Demux, each output of which is connected to a different input of $n \times n$ optical switch X11. Each output of optical switch X11 is connected to a different one of tributary cards $TC_1, TC_2 \dots TC_n$ such that the signal on each carrier
 25 received from optical guide OG may be flexibly routed to any tributary card. Each

tributary card $TC_1, TC_2 \dots TC_n$ typically contains a photo-detector for conversion of the optically modulated signal into the electrical domain. The reflective routing arrangement of the transmitter is not necessary in the receiver as photo-detectors are available which can efficiently detect signals across a spectral band greater than
 5 100nm, i.e. sufficient to cover the bandwidth of a typical WDM system.

Lasers $L_1, L_2 \dots L_n$ could comprise a semiconductor diode laser having an inbuilt frequency stabilising grating such as a distributed feedback (DFB) diode laser. Alternative types of laser include semiconductor diode distributed Bragg reflector
 10 (DBR) laser, a fibre Bragg laser or distributed feedback fibre laser constructed using erbium doped fibre and pumped using a diode laser. Such lasers may be constructed in an array format to give regular spacing of the output ports which may make optical alignment more practical.

15 The optical circulators $C_1, C_2 \dots C_n$ may be of a type using a calcite beam splitter. As an alternative to the optical circulators a polarisation beam splitter (PBS) arrangement may be used in combination with an arrangement for rotating the polarisation of the light between leaving the PBS for the modulator and returning to the PBS, such as a suitable Faraday rotator crystal and magnet. The polarised light passes through the
 20 PBS into port 1 and then it exits port 2 into the modulator then the plane of polarisation is changed by 90 degrees before it is put into the PBS again at port 2 to be reflected back out of port 3 to the multiplexer. Lasers commonly produce polarised radiation and so a PBS or a circulator of a type capable of handling just one polarisation may be sufficient. This makes construction less complex compared to a

polarisation diverse optical circulator and facilitates use of an integrated multiport circulator.

The optical switches X1, X2, X10, X11 may be based on a thermally switched
 5 waveguide type, a type based upon the evaporation of a liquid at each crosspoint, on movement of a liquid at the crosspoint, or on mechanical movement of a miniature mirror or diaphragm.

The optical modulators $EOM_1, EOM_2 \dots EOM_n, EO_1, EO_2 \dots EO_n$ may be an electro
 10 absorption waveguide or reflecting Fabry-Perot type semiconductor diode, electro optic interferometric (such as Mach Zehnder) type, or a modulated semiconductor optical amplifier, or a micro mechanical reflective fast switch.. The Electro absorption modulators are based on reverse-biasing of a semiconductor diode to vary the loss and could be used in a reflective arrangement. Alternatively, the modulatable
 15 semiconductor optical amplifier could be used in a reflective mode.

Alternatively, the above modulators may comprise an electrostatically actuated diaphragm reflector implemented in a silicon fabrication.

20 The optical multiplexing may be achieved by means of a dielectric mirror combination, a diffraction grating spectrometer and array waveguide (AWG) spectrometer arrangements.

Single switch with a transmissive modulator

The absorption edge semiconductor (reflective) modulator has been demonstrated in the literature to be capable of high speed modulation to beyond 40Gbit/s. However, with such modulators the best operation is obtained for a range of wavelengths close to the band edge of the semiconductor used in the core of the waveguide. This is the
5 range of wavelengths where the refractive index changes sufficiently greatly with bias for efficient modulation and sufficiently slowly with bias to provide low chirp in wavelength under modulation. In the arrangement of Fig. 7 any wavelength carrier can be delivered to any modulator, so the deviations from the above optimum condition may affect performance.

10

According to a further preferred embodiment, transmissive modulators (i.e. modulators that transmit the modulated carrier), such as Mach-Zehnder modulators are used. Advantageously, Mach-Zehnder modulators are effective over a wide range of carrier wavelengths. A Mach-Zehnder modulator may be used in reflective mode
15 in the arrangement of Figure 7. For very high bit rates a travelling wave Mach-Zehnder modulator device is very effective for modulation of transmitted light in a two optical port arrangement but is less effective in a reflective arrangement.

Figure 8 shows an arrangement according to a further preferred embodiment using
20 transmissive "two-optical port" modulators such as travelling wave Mach-Zehnder modulators, optical amplifiers and also electro absorption semiconductor types. The arrangement here is similar to that of Figure 7. Elements common to both figures have been given the same references and will not be described further here.

Instead of being connected directly to the optical modulators, as in Figure 7, the outputs of optical switch X10 each connect to a different one of plurality of optical circulators $C_{11}, C_{12} \dots C_{1n}$. Each one of optical circulators $C_{11}, C_{12} \dots C_{1n}$ transmits the light received from the respective output port of switch X10 to a different one of transmissive modulators $TEO_1, TEO_2 \dots TEO_n$. Each transmissive modulator $TEO_1, TEO_2 \dots TEO_n$ outputs the received carrier modulated with the signal received on the respective electrical input $S_1, S_2 \dots S_n$ to a third port on the respective optical circulator. Each optical circulator $C_{11}, C_{22} \dots C_n$ passes the modulated carrier received at the third input thereof for output at the first port thereof, i.e. the port at which it received the unmodulated carrier from optical switch X10. Hence the modulated carrier is coupled back (as in the arrangement of Figure 7) into optical switch X10 at the same port as that used to output the unmodulated carrier. Transmission of the modulated carriers to the optical guide OG is achieved in a similar way to that described above, with reference to Figure 7.

15

Again, if a single-polarisation light source is used, the circulators can be of a single-polarisation type which is less complex than the polarisation-diverse optical circulator.

20 Hybrid Integration

In Figures 5 to 8 the component count is quite large. However, many of these components have a similar function, advantageously creating the possibility of integration. Semiconductor laser arrays may be used in place of discrete lasers. These may be DFB diode laser arrays, or a semiconductor amplifier array could be

used with a diffraction grating arrangement to produce a WDM array source. An array of semiconductor optical amplifiers (SOAs) may be assembled together with a silica or silicon waveguide arrangement in such a way as to achieve an array of external cavity laser sources. The wavelength selective reflectors can be integrated by
 5 imposing Bragg reflective gratings into the waveguide as refractive index variations by means of etching or compositional diffusion induced by UV irradiation as are now well known technologies. An array of fibre DFB lasers may be used – the lasers aligned using a silicon V groove optical bench arrangement.

10 A plurality of circulators may also be integrated into a single multi-channel optical device as described in co-pending application GB 98 26 108 in the name of Marconi Communications. If fibre lasers are placed 250 microns apart, a 32 channel circulator could be produced less than 1cm wide. An array of optical modulators with 250 micron to 1000 micron spacings is quite practical.

15

The configuration of Figures 7 or 8 may be implemented as a hybrid integrated device or alternatively as a compact system interconnected by means of optical fibres and collimating lenses and or free space optical beams.

20 Figure 9 illustrates the operation of the optical circulator C_{1p} connected between output port p of optical switch X_{10} and optical transmissive modulator TEO_p . Unmodulated carrier λ_m is output from port p of switch X_{10} and passes through circulator C_{1p} from ports 1 to 2 then on to modulator TEO_p where it is modulated with the signal S_p from the electrical input to form modulated carrier $(\lambda_m + S_p)$. Modulated

carrier ($\lambda_m + S_p$) is output from modulator TEO_p and passes back through the circulator C_{1p} from ports 3 to 1 thereof and back to port p of switch X10.

Advantageously amplifiers may be placed between the light sources and the
5 modulators, preferably after the switch as the losses in the switch could be significant.
The amplifiers could be SOAs or fibre or slab waveguide types.

CLAIMS

1. An Optical Communications System comprising one or more light sources each for producing light in a different part of the spectrum;

a plurality of optical modulators each for modulating with an input signal the light produced by the one or more light sources;

an optical switch connected between the one or more light sources and the plurality of optical modulators for switching the light output from the or each of the light sources to a different selected one of the plurality of optical modulators.

2. The Optical Communications System as claimed in Claim 1 in which the optical switch is connected to the plurality of optical modulators for switching the modulated light output from the selected one or ones of the plurality of optical modulators.

3. The Optical Communications System as claimed in any one of Claims 1 and 2 in which the optical switch is connected between the one or more light sources and the plurality of optical modulators for passing to a selected one of the plurality of optical modulators via a selected path in a first direction the light output by the or one of the light sources and for passing via the selected path in the opposite direction the modulated light output from the selected one of the plurality of optical modulators.

4. The optical communications system as claimed in any above claim also comprising one or more optical routing means in which the or each light source is connected to the optical switch via the one or more optical routing means.

5. The optical communications system as claimed in Claim 4 also comprising an optical multiplexer comprising a plurality of inputs;

in which the modulated light output from each of the selected one or ones of the plurality of optical modulators is connected to a different one of the plurality of optical multiplexer inputs via the optical switch and the at least one optical routing means.

6. The optical communications system as claimed in Claim 1 also comprising a second optical switch for switching the modulated light output from each of the selected optical modulators.

7. The optical communications system as claimed in Claim 6 also comprising an optical multiplexer comprising a plurality of inputs;

in which the modulated light output from each of the selected ones of the plurality of optical modulators is connected to a different one of the optical multiplexer inputs via the second optical switch.

8. The optical communications system as claimed in any above Claim in which the optical modulators are reflective.

9. The optical communications system as claimed in any one of Claims 1 to 7 as dependent from Claim 4 in which the optical modulators are transmissive;

in which the system also comprises one or more a second optical routing means in which each optical routing means of the second plurality comprises a first port for receiving light from the or one of the light sources via the optical switch;

in which the or each optical routing means also comprises a second port for passing the light received at the first port to a different one of the optical modulators and a third port for receiving modulated light from the respective one of the optical modulators, for passing to the first port for output.

10. The optical communications system as claimed in any one of claims 4, 5 and 9, in which the optical routing means and/or the second optical routing means comprise one or more optical circulators.

11. The optical communications system as claimed in any one of claims 4, 5 and 9, in which the optical routing means and/or the second optical routing means comprise one or more polarisation beam splitters.

12. An optical communications system substantially as described with reference to and as illustrated in figures 5 to 9 of the drawings.



INVESTOR IN PEOPLE

Application No: GB 0101521.3
Claims searched: 1-12

Examiner: Stephen Brown
Date of search: 14 January 2002

Patents Act 1977 Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.T): H4B (BK14D2D, BKX, BN)

Int CI (Ed.7): H04B: 10/155, H04J: 14/02.

Other: Online: WPI, EPODOC, JAPIO.

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 6 137 613 (NEC) See especially the abstract, figures 3-6, & column 4, line 53, to column 5, line 30.	1, 4, & 6

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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